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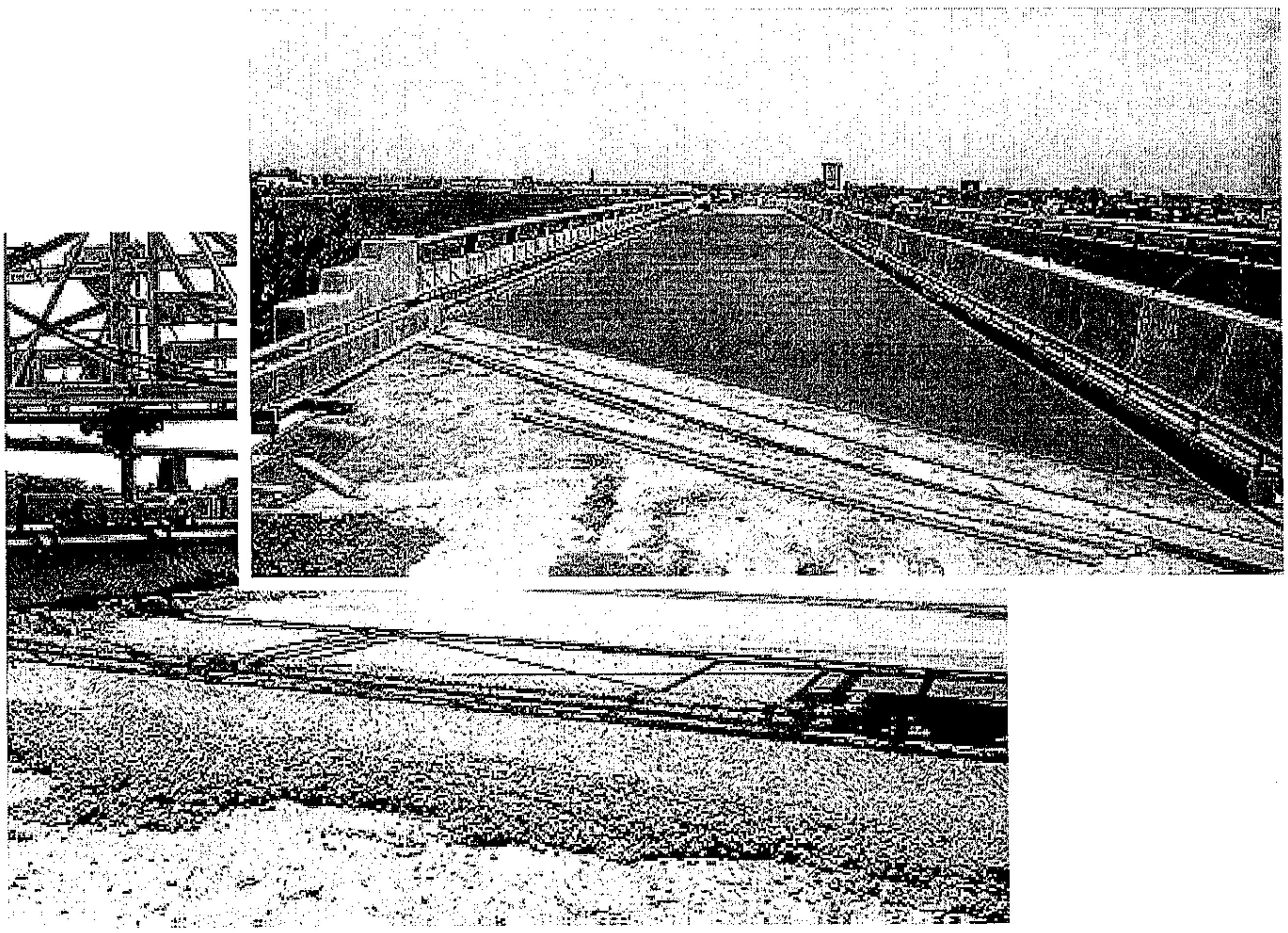
Concrete Bridge Deck Overlays in Illinois:

Mix Design Experimentation and Investigation of Construction Methods



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CONCRETE BRIDGE DECK OVERLAYS IN ILLINOIS: MIX DESIGN EXPERIMENTATION AND INVESTIGATION OF CONSTRUCTION METHODS

by

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16. Abstract

The purpose of a bridge deck overlay is to extend the life of a structure by providing a durable wearing surface and a barrier against chloride intrusion. The majority of the deck overlays in Illinois' recent past have contained microsilica. Problems associated with microsilica deck overlays, such as rapid slump loss, poor constructability, and shrinkage cracking, prompted the development of three alternative mix designs and a subsequent field evaluation. In Design 1, the microsilica content was dropped from 50 to 33 lbs/yd^3. Design 2, a ternary mix design, contains cement, microsilica, and Class C fly ash. Design 3, which contains fly ash and no microsilica, has a 25% cement replacement rate at a 1.5:1 replacement ratio. All three designs share changes in coarse aggregate gradation, proportion of coarse and fine aggregate, and water-cement ratio.

Twenty-one bridge deck overlays were included in the field evaluation of the three mix designs. All of the overlays used the new designs and were constructed in 1998. Construction observations are reported as well as various test results, including flexural strength, rapid chloride permeability (Illinois Modified AASHTO T 277), salt ponding and chloride ion content, and tensile strength of bond (pull-off). Also, initial distress surveys of all 21 structures were performed between three and six months after the overlays were placed.

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EXECUTIVE SUMMARY

The purpose of a bridge deck overlay is to extend the life of a structure by providing a durable wearing surface and a barrier against chloride intrusion. In order to achieve low permeability, microsilica is commonly added to concrete. Problems associated with microsilica deck overlays, such as rapid slump loss, poor constructability, and shrinkage cracking, prompted the development of three alternative mix designs and a subsequent field evaluation. In Designs 1 and 2, the microsilica content was lowered from 50 to 33 lbs/yd^3. Design 2, a ternary mix design, contains cement, microsilica, and Class C fly ash. Design 3, which contains fly ash and no microsilica, has a 25 percent cement replacement rate at a 1.5:1 replacement ratio. All three designs share changes in coarse aggregate gradation, proportion of coarse and fine aggregate, and water-cement ratio.

Twenty-one bridge deck overlays were included in the field evaluation of the three mix designs. All of the overlays used the alternative designs and were constructed in District 6 in 1998. Relative humidity, wind speed, air temperature, and concrete temperature were measured and evaporation rates were calculated during 10 of the pours. At some point during each of those pours, conditions were severe enough for plastic shrinkage cracking to occur without preventative measures. Measures taken to prevent cracking included mounting fogging nozzles on the paving machine and applying curing compound immediately behind finishing and texturing. Earlier application of wet burlap may have prevented plastic shrinkage cracking. On at least one occasion, the wet burlap was not placed until more than four hours after curing compound application.

Flexural strengths for the three alternative mix designs were above specifications limits. Design 3 had slightly lower flexural strengths, and Designs 1 and 2 had similar flexural strengths compared to the standard design in District 6 (1996 and 1997

construction seasons). Two types of permeability tests were performed: chloride ion content testing of salt ponding samples, and rapid chloride permeability (RCP) testing. The ternary design (Design 2) had the lowest indicated permeability of the three alternative designs and the present design. The use of fly ash in combination with microsilica not only densified the concrete further, but it enhanced workability and allowed for a lower water-cement ratio. Design 1 performed similarly to the standard design, having slightly lower permeability as indicated by chloride ion content testing of salt ponding slabs, but slightly higher RCP test results.

Initial distress surveys, performed between three and six months after construction, indicated that initial performance was very good. Minor cracking was found in only seven of the 42 lanes, all of which were in Stage I. Cracking in three of the lanes can be attributed to materials-related problems. Minor cracking can be attributed to construction problems in three other lanes. There is no clear explanation for the distresses found in the remaining lane.

Design 1 replaced the standard design in the specification for microsilica concrete bridge deck overlays in March of 1999, and Design 2 may be used at the contractor's option. Design 3 may be considered for limited applications, pending long-term performance data. Since Design 3 has the highest permeability of the three designs, its use should be limited.

The following are construction recommendations based on findings of the study:

1. Evaluate effectiveness of high-pressure water blasting. Use the pull-off test to determine whether the microfractured layer has been removed.
2. Do not allow water to be applied to the cleaned deck surface within one hour before or anytime during concrete placement.
3. Apply wet burlap sooner.

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INTRODUCTION

Bridge Deck Overlays

The purpose of a bridge deck overlay is to extend the life of a structure by providing a durable wearing surface and a barrier against chloride intrusion. Many older bridge decks in Illinois are beginning to suffer distresses as a result of corrosion of the reinforcing steel. Corrosion can commence after a sufficient amount of chloride ions permeate through the deck to the steel. A deck overlay made with low permeability concrete can reduce chloride ion penetration and should thus slow the progression of corrosion.

The condition of a bridge deck at the time of an overlay varies. When a deck is still in good condition (i.e., no sign of corrosion or delaminations in the deck), its life span can be extended greatly by placing an overlay and preventing additional chlorides from intruding. A deck that has already started to suffer from corrosion but is otherwise in good condition can also benefit, albeit from a shorter lifetime extension. These two distinct circumstances do not require the same level of performance from an overlay. In the first case, the overlay is expected to prolong the life of the bridge for an extended period of time, possibly up to 20 years or more. However, if the bridge is already in fair to poor condition, the overlay may only prolong its life by 10-15 years.

Bridge Deck Overlay Mix Designs

In order to achieve low permeability, bridge deck overlay mix designs normally contain one or more pozzolans. Two pozzolans are included in this study: microsilica and Class C fly ash. However, other pozzolans and cementitious materials are available in other areas of the country and recently have become available in Illinois. A separate evaluation of high-reactivity metakaolin is currently underway, and ground-granulated blast furnace slag will soon be more readily available in Illinois.

The most commonly used type of overlay mix design in Illinois in recent history has been the microsilica concrete design. The Illinois Department of Transportation (IDOT) has placed more than 175 microsilica concrete bridge deck overlays since the mid-1980's. Microsilica is a pozzolan that consists of at least 85 percent silicon dioxide. The silicon dioxide reacts with calcium hydroxide, a byproduct of cement hydration. This pozzolanic reaction increases strength and lowers permeability by densifying concrete.

While many microsilica overlays have performed well, a variety of problems have been observed. A small number of overlays have been partially or completely removed and replaced due to debonding. Also, several overlays placed in District 1 have experienced severe pop-outs after freeze-thaw cycling due to balling or flocculation of microsilica particles. The most prevalent problem experienced with microsilica concrete overlays has been cracking. Both plastic and drying shrinkage cracks are common in the overlays placed thus far. The most significant consequence of this cracking is a localized increase in permeability. At crack locations, the overlay no longer accomplishes its mission as a chloride barrier, and, since reinforcing cover has been reduced by milling, corrosion can progress more rapidly than before.

Fly ash can be used in combination with microsilica to further lower concrete permeability. Since only a small amount of Class F fly ash is available in Illinois, only Class C fly ash was evaluated in this study. Class C fly ash is both cementitious and pozzolanic. Since Class C fly ash contains a much smaller proportion of pozzolanic material compared to microsilica, it is not as effective at lowering permeability. The three greatest advantages of using fly ash are that it enhances workability, lowers permeability, and is less than half the cost of Type I cement.

PROBLEM STATEMENT

Water Demand

The IDOT "Bridge Deck Microsilica Concrete Overlay" Special Provision (Effective May 1995 to March 1999) outlines a specific mix design and requires that the water-cement ratio be between 0.36 and 0.39, as shown in Table 1. The special provision also requires slump to be between 3 and 6 inches. In practice, these two conditions cannot consistently be met simultaneously.

In most instances, a water-cement ratio of 0.39 results in a zero-slump mix. An extremely large dosage of a high-range water-reducing admixture (HRWRA), or superplasticizer, is required in order to increase slump to an acceptable level. However, superplasticizers are designed to increase slump from about 2 to 6 inches or more, not from 0 to 6 inches. If the mix is initially too dry, then the HRWRA is ineffective until a very large dosage is added. Not surprisingly, the greater the slump increase due to the HRWRA, the more rapid the slump loss. As a result, finishing operations can be delayed due to the loss of workability, and a larger labor force may be required.

The standard microsilica bridge deck overlay design has a very high water demand. The water demand is affected primarily by three factors: the amount of microsilica, the combined aggregate gradation, and the angularity of the aggregates. Microsilica particles are approximately 100 times smaller than cement particles. Accordingly, the addition of microsilica to a concrete mixture increases the water demand considerably. This effect was demonstrated in laboratory mixes, where microsilica was estimated to have a water demand 2.3 times that of cement.

The standard design also has a very low coarse aggregate to fine aggregate ratio (CA/FA, by volume). A typical IDOT bridge deck mix design has a CA/FA between 1.45-1.55. The standard design has a CA/FA of only 1.07. The total surface area, as well as the water demand, increases as CA/FA decreases. The combination of the amount of microsilica and the low CA/FA creates a very high water demand compared to a conventional concrete mix design.

Table 1.
Standard IDOT Microsilica Concrete Mix Design (Effective 5/95 to 3/99)

Coarse Aggregate	1600
Fine Aggregate	1500
Cement	550
Microsilica	50
W/C Ratio	0.36 - 0.39

NOTE: All weights are lbs/yd^3

Constructability

The standard design exhibits rapid slump loss and is very difficult to finish. In many instances, finishing operations have fallen far behind placement. Not only does this distinction increase bid prices, but it also has the potential to delay curing operations. Such delays can lead to plastic shrinkage crack formation due to evaporation loss.

Another repercussion of poor workability is that it often leads to additional watering during finishing. The fogging equipment that is specified to prevent plastic shrinkage can be misused to pond water on the unfinished surface. This water is then finished into the top of the overlay, resulting in a thin, weak layer that subsequently scales off.

Plastic and Drying Shrinkage Cracking

Both plastic and drying shrinkage cracking have been observed in a number of microsilica deck overlays. The potential for plastic shrinkage cracking of microsilica concrete is very high due to the low water-cement ratio and the blocking of capillary pores by the extremely fine microsilica particles. Moreover, a bridge deck overlay has a very large surface area in relation to its volume. With such a large area exposed to evaporation, a bridge deck overlay is highly susceptible to plastic shrinkage cracking.

Plastic shrinkage occurs when evaporation from the surface of the concrete causes a volume decrease while concrete is still plastic. If this volume decrease causes stresses that are greater than the tensile strength of the concrete, then cracks form. The major factors that affect the rate of evaporation are: fresh concrete temperature, ambient air temperature, relative humidity, and wind speed. The rate of evaporation, normally expressed in pounds of water lost per square foot per hour ($lb/ft^2/hr$), can be estimated using an ACI nomograph or an algebraic formula [*1,2*].

If the evaporation rate exceeds 0.2 $lb/ft^2/hr$ in conventional concrete, then plastic shrinkage cracks are likely to develop. Microsilica concrete, however, may develop shrinkage cracks at a lower rate, as low as 0.1 $lb/ft^2/hr$. An effective method of preventing plastic shrinkage cracking is fogging the surface of the overlay with a fine mist of water. The mist increases the relative humidity and as a result lowers the evaporation rate. Applying curing compound as soon as possible after finishing will also help to prevent plastic shrinkage.

Another factor that can affect evaporation loss is the degree of sunlight. Direct sunlight will elevate the temperature at the surface of the concrete and will consequently accelerate evaporation. Overcast days, however, may not provide protection. Direct sunlight, while increasing the evaporation rate compared to overcast conditions, also accelerates strength gain [2]. The strength gain may be sufficient to resist shrinkage forces and prevent cracking.

ALTERNATIVE MIX DESIGNS

In order to address the concerns associated with the standard microsilica mix design, including water demand, constructability, and shrinkage, several changes were proposed and three alternative mix designs were formulated and later evaluated in the field.

Lower Microsilica Content

The microsilica content was decreased in Designs 1 and 2, as shown in Table 2, in order to alleviate water demand and constructability problems. The decrease in microsilica content lowered water demand by about 12 lb/yd^3 in laboratory mixes. This translates into a water-cement ratio decrease of 0.02.

The lowering of microsilica content by itself would increase permeability. However, this slight increase in permeability due to the removal of microsilica is partially offset by the corresponding drop in water-cement ratio made possible by the mix design changes. As water-cement ratio decreases, concrete density will increase. As a result, permeability will decrease.

Increase CA/FA

One significant change in all of the alternative designs is in CA/FA. The standard design has a CA/FA of about 1.07, depending on the actual water-cement ratio. Designs 1, 2, and 3 have CA/FA values of 1.38, 1.45, and 1.44, respectively. An important effect of this change is that the total surface area of the combined aggregate gradation will decrease significantly.

Coarse Aggregate Gradation Change

At the request of District 6, two alternative coarse aggregate gradations were used. In the past, the majority of bridge deck overlays have incorporated a CA16 gradation.

However, since the minimum specified overlay thickness has been increased to 2.25 inches, gradations with larger top sizes are feasible. Both CA11 and CA14 gradations were used on the three contracts included in this study. Table A-1 compares the three gradations. The most significant difference between the CA16 and the CA11 and CA14 is in the percent passing the No. 4 sieve. The water demand of CA16 is high due to the large amount of material passing the No. 4 sieve.

Design 2: Ternary Design

The second design that was evaluated contained three cementitious/pozzolanic materials: cement, fly ash, and microsilica. Class C fly ash replaces 15 percent of the cement at a 1.5:1 ratio. The replacement of cement with fly ash has the potential to decrease water-cement ratio by 0.01 to 0.03, depending on the physical properties of the fly ash. Also, fly ash lowers permeability through a pozzolanic reaction. Design 2 has the lowest attainable permeability of the three designs, as well as the lowest water-cement ratio.

Table 2.
Alternative Mix Designs

	Design 1	Design 2	Design 3
Coarse Aggregate	1753	1753	1753
Fine Aggregate	1245	1195	1187
Cement	572	485	515
Microsilica	33	33	--
Fly Ash	--	135	140
W/C Ratio	0.40	0.37	0.38

NOTE: All weights are lbs/yd^3; designs based on air content of 6.5%

Design 3: Fly Ash Design

Design 3 is based on a conventional IDOT bridge deck mix design with 605 lb/yd^3 of cement. Fly ash replaces 15 percent of the cement at a 1.5:1 ratio. The coarse aggregate content of the design is the same as Designs 1 and 2. Again, due to the replacement of cement with fly ash, a low water-cement ratio is possible. The early strength gain of concrete containing Class C fly ash can be faster or slower than the strength gain of a cement-only design, depending on the chemical and physical properties of the fly ash. Normally, Class C fly ash slightly accelerates early strength gain.

The permeability of Design 3 will depend on the properties of the Class C fly ash used. As the amount of pozzolanic material increases in fly ash, permeability decreases. Regardless of the properties of the fly ash, Design 3 will have slightly higher permeability than the present design, as well as Designs 1 and 2.

PRELIMINARY LABORATORY TESTING

In 1997, the Bureau of Materials and Physical Research studied the effect of microsilica on permeability. Microsilica contents varied between 0 and 10 percent, and permeability was measured using Illinois Modified AASHTO T 277, "Electrical Indication of Concrete's Ability to Resist Chloride," more commonly referred to as the rapid chloride permeability (RCP) test. RCP tests were performed after samples cured for 28 days. As shown in Figure 1, no significant benefit is gained by using microsilica contents beyond about 6 to 7 percent. A more in-depth study of microsilica concrete concluded that "contents greater than about 6 percent are unnecessary for bridge deck applications" [*3*].

After permeability testing, four lab mixes were evaluated to roughly determine a practical field water-cement ratio range. Each of the four mixes was based on four different district mix designs and contained aggregates that were used in those mixes. Water-cement ratios were between 0.41 and 0.45 at very high superplasticizer dosages.

Microsilica content and water-cement ratio were lowered in the next set of trials. Two trial batches similar to Design 1 were mixed in the laboratory in order to establish a starting point for the water-cement ratio that was to be used in the first batch in the field. Two ready-mix plants were to supply concrete for the three I-72 contracts: Capitol Ready-Mix in Springfield and Community Ready-Mix in Jacksonville. The first trial batch contained coarse aggregate, fine aggregate, and cement sampled from the ready-mix plant in Jacksonville. The second trial batch contained coarse aggregate, fine aggregate, and cement from the Springfield ready-mix plant. The chemical admixtures used in both trial batches were of the same type used at both plants.

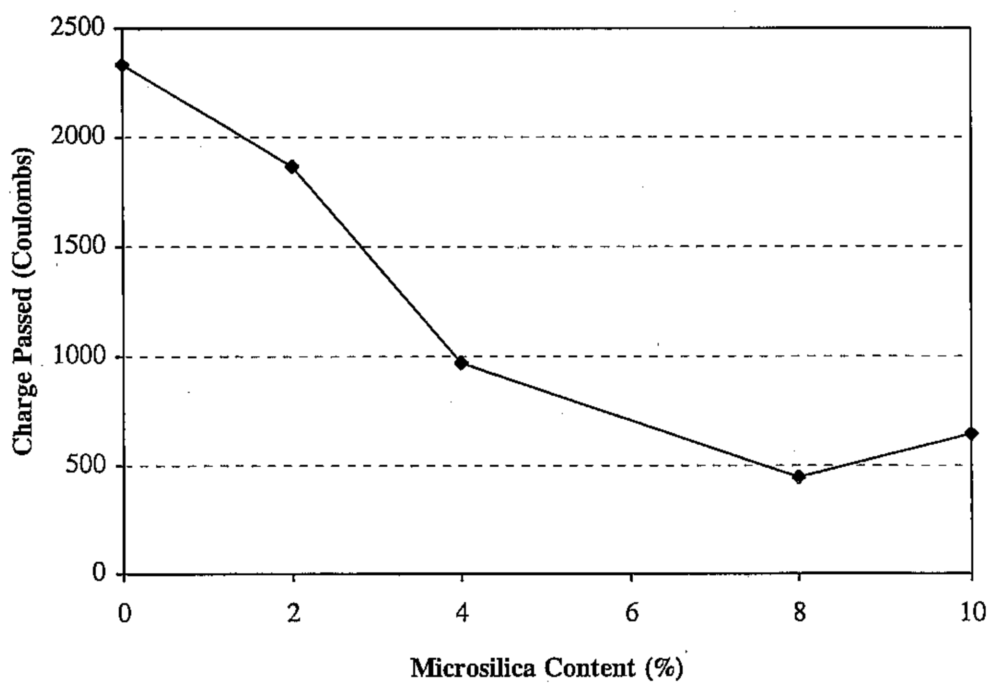

Figure 1.
Microsilica Permeability Testing

One notable difference between the laboratory mix and the field mixes was the use of a mid-range water reducer in the field mixes for Designs 1 and 2. A mid-range water reducer was added at the plant in order to increase slump before microsilica was added.

FIELD EVALUATION OF MIX DESIGNS

The field evaluation of the alternative mix designs included three contracts that consisted of 21 concrete bridge deck overlays. Twenty of the bridges are located between Springfield and Jacksonville on Interstate 72 in Sangamon and Morgan Counties. One of the bridges carries US 67 over I-72 near Jacksonville in Morgan County. Contract numbers and bridge locations are listed in Table B-1. Each bridge deck was overlaid in two stages. Stage I consisted of the driving lanes of the I-72 bridges and the southbound lane of the US 67 bridge. Stage II included the I-72 passing lanes and the northbound lane of US 67.

Design 1 was utilized in 39 of the 42 separate deck overlay pours. Design 2 was used on two lanes during Stage I, and Design 3 was used on one lane during Stage II. Stage I deck overlays were placed between May 14 and June 24, 1998. Stage II overlays were constructed between July 7 and August 17, 1998. Pour dates are found in Table B-1.

Bridge Condition and Deck Patching

All of the structures were between 20 and 29 years old in 1998. With the exception of two structures, bituminous membrane waterproofing systems were placed at the time of original construction. The bituminous surfaces of those decks were in poor condition and had required repairs varying from cold patch applications to a new bituminous overlay on one structure. The two decks that were still bare had been patched in 1986.

Deck soffits were, overall, in fair to good condition at the time of the overlays. Delaminations were typically at expansion joints. Most deck soffits had light transverse cracking, and some areas were delaminated. Table B-2 describes soffit conditions for each structure, as well as condition ratings and other information.

Partial depth patches were necessary on all of the structures. Passing lanes on two structures, however, used an alternative repair method. Approximately 75 percent of the deck area required patching in these two lanes. District 6 decided to forego patching rather than patch such a large percentage of the deck. Instead, the lanes were milled to just above the top layer of reinforcing steel, and an additional 1 1/2 to 2 inches were added to the overlay thickness. Four of the remaining 40 lanes required more than 5 percent partial depth patching. Only two lanes required full depth patches. Table B-3 contains patching quantities for all of the structures. IDOT bridge deck overlay selection guidelines specify a range of 5 to 35 percent patching for all concrete deck overlays.

Admixtures and Mixing Sequence

An air entraining admixture and a mid-range water reducer were added at the plant with the aggregates, water, and cement. A water-reducing retarder was also added when the air temperature was above 65° F. After initial mixing (30-40 revolutions), the microsilica was added in 50 lb increments from bags: one bag per 1.5 yd^3, or four bags per 6 yd^3 truckload. Then, after 70-80 additional revolutions, the mix was transported to the job site where the superplasticizer was added. The addition of a mid-range water reducer at the plant resulted in a more efficient mixing action and greatly reduced the amount of superplasticizer necessary in the field to achieve the desired slump.

CA/FA

The increase in the CA/FA resulted in a marked improvement in finishing. As stated earlier, the standard design contains a very large amount of fine aggregate. This excessive amount of fine aggregate caused the mix to be difficult to finish. The alternative designs are comparable to a typical IDOT concrete mix in workability and ease of finishing.

Design 2: Ternary Design

The replacement of cement with fly ash lowered water demand by about 8 percent. During the first pour, on the morning of June 1, 1998, a very low water-cement ratio of 0.35 was used. A few golf ball to baseball-size pieces of fly ash were pulled out of the mix. In the afternoon, the water-cement ratio was increased to 0.37 and the fly ash did not "ball." The most likely explanation for this problem is that there was not sufficient water in the mix to facilitate mixing of the fly ash at the plant, but slump was attainable with superplasticizer at the job site. Finishing characteristics were similar to Design 1 and much improved over the standard microsilica design.

Design 3: Fly Ash Design

Design 3 was placed at a water-cement ratio of 0.38. No mid-range water reducer was added at the plant, and less superplasticizer was required than in Designs 1 and 2. Only two of the four fogging nozzles were used. Finishing characteristics were about the same as Designs 1 and 2. No fluctuations in air content were experienced; however, only three truckloads were required for the lane.

CONSTRUCTION OBSERVATIONS

Surface Preparation

The bridge decks were prepared for overlays in the following manner, with exceptions noted:

1. Remove the existing waterproofing membrane system (except two bare decks).
2. Sound the deck surface and mark areas to be patched.
3. Place and cure the partial and full depth patches.
4. Scarify (mill) the deck to a depth of approximately 3/8-inch (except two lanes that were removed to top layer of reinforcing steel).
5. Wash the deck with power washing equipment (two lanes sandblasted).
6. Sound and cut additional partial depth patches (small quantities).
7. Wash the deck with power washing equipment and keep covered with polyethylene sheeting until just before placement.
8. Pour the remaining partial depth patches with overlay.

The two lanes that were sandblasted had been milled during a light rain. The Resident Engineer noticed a film on the surface of the two decks and subsequently required the contractor to sandblast the surfaces.

Concrete Construction

All of the overlays were fogged in order to lower the evaporation rate just above the surface of the fresh concrete. During construction of the first few decks, a hand operated four nozzle spray bar was used from the finishing work bridge. Hand-held pump sprayers were also used to add water to facilitate finishing. On the remaining pours, fogging nozzles were mounted on the paver (two on each side), and hand-held pumps were no longer used. However, the fogging was used before finishing instead of after. Water ponded on the surface of the concrete and was finished into the deck by a bull float or straight edge. A watery mortar was dragged across the surface by the float. In several instances, fogging nozzles were not turned off when the paver stopped to wait for another ready-mix truck.

During several pours, large amounts of water ponded in front of paving operations along the parapet walls. The water was applied by laborers using hoses attached to the ready-mix trucks. These bridges were on superelevations, and sloped longitudinally towards the pour. While efforts were made to brush water away from the front of the pours, the water quickly returned and mixed into the fresh concrete. This excess water significantly increased the water-cement ratio in the concrete near the parapet wall. Later in the summer, a wet-dry vacuum was used to remove excess water in front of the paver, especially water ponded in partial depth patches that were poured with the overlay.

Concrete Curing

In the interest of expediency, the contractor was allowed to place two lanes in one day. However, on several occasions, the contractor did not begin curing with wet burlap until the next morning. When a set retarder was used on a hot, overcast afternoon, the overlay was not strong enough to support laborers for more than four hours. The consequence of this action was that durability was sacrificed due to the delay in wet burlap application. While curing compound does impede evaporation, it is merely a temporary measure, and it does little to slow temperature fluctuations.

The purpose of wet burlap curing is twofold. First, it prevents the loss of moisture during the critical first week of hydration and strength development and allows the concrete the time it needs to gain sufficient strength to resist shrinkage forces. Secondly, it acts as an insulator to slow the rate of temperature fluctuations. A large temperature swing, especially during the first 24 hours when the concrete has relatively low tensile strength, can lead to cracking. A layer of wet burlap will protect the overlay from rapid temperature fluctuations.

Plastic Shrinkage Cracking

Relative humidity, wind speed, air temperature, and concrete temperature were collected for 10 pours during nine days. This data was used to calculate evaporation rates. Evaporation rates for specific days are listed in Table B-4. During all of these pours, the evaporation rate exceeded the critical value where cracking is a risk for microsilica concrete (0.1 $lb/ft^2/hr$). However, when conditions were at their worst during the pours, plastic shrinkage cracking was either prevented or minimal.

Figure 3 shows evaporation rates for May 14 and July 16, 1998. Two lanes were placed on each of the days. Plastic shrinkage cracking was later found on the lane poured in the morning of May 14. The plastic shrinkage cracking was primarily due to a delay in application of curing compound. In the area containing the cracks, the curing compound application was approximately two hours after placement. During the afternoon of May 14, curing compound application was immediately behind finishing operations. No plastic shrinkage cracking was found, despite more severe conditions.

On the morning of July 16, evaporation rates quickly exceeded critical levels. Despite severe conditions, plastic shrinkage cracks were prevented. This success was due to the use of fogging equipment and the application of curing compound as close as possible behind finishing and texturing operations.

One other lane contained a significant amount of plastic shrinkage cracks. In this case, cracking was due in part by excessive set retardation. The excessive retardation was caused by the unintentional use of a different retarding admixture. Wet burlap, consequently, was not placed until the morning after the pour on the driving lane of

Structure 069-0056. The extended delay in the placement of burlap allowed enough moisture loss through the curing compound to cause cracking. The same retarding admixture was also inadvertently used in a portion of the driving lane of Structure 069-0055, which contained a small area of plastic shrinkage cracking.

Small areas of plastic shrinkage cracking were also found in the driving lanes of Structures 069-0148 and 0149. Both of the lanes were placed on May 18, 1998. The evaporation rate at 10:55 a.m. on that day was 0.43 lb/ft²/hr. During such extreme conditions, minor cracking is almost impossible to prevent without continuous fogging or immediate application of wet burlap from a separate work bridge.

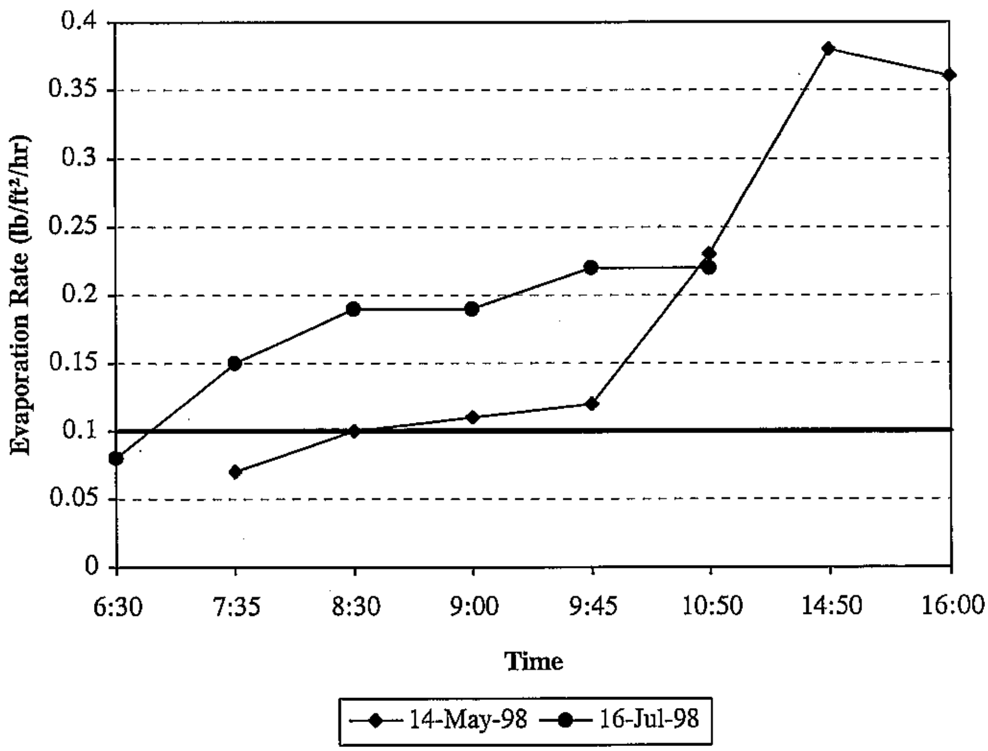

Figure 2.
Evaporation Rates During Construction

TEST RESULTS

Flexural Strength Testing

District 6 Construction tested flexural strength specimens at 7 and 14 days. Average flexural strengths can be found in Table 3. Table 3 also contains District 6 microsilica strengths from five contracts completed in 1996 and 1997 that used the standard mix design. The difference in flexural strength between the new design and 1996-97 test results is minor. The mean 7- and 14-day flexural strengths were lower for Design 1, but by only 86 and 83 psi, respectively. The comparable performance in strength is expected since both the lower water-cement ratio and slightly higher cement content in Design 1 partially offset the effect of the lower microsilica content.

Slightly higher flexural strengths were attained with the ternary design (Design 2): 969 psi at 7 days and 993 psi at 14 days. Design 3 had the lowest flexural strengths: 818 psi at 7 days and 829 psi at 14 days. All of the flexural strengths are well above the requirements of the special provision (675 psi at 7 days).

Table 3.
Flexural Strength Data

	7-day (psi)		14-day (psi)	
	Mean	SD[a]	Mean	SD[a]
Design 1	851	77	952	67
Design 2	969	--	993	--
Design 3	818	--	829	--
Standard Design	937	56	1035	173

[a]Standard Deviation
NOTE: Design 1 data based on 52 and 54 individual tests (7- and 14-day strengths, respectively); Standard Design data based on 14 and 16 tests (7- and 14-day strengths, respectively)

Salt Ponding and Chloride Ion Content Testing

Salt ponding testing was performed according to Illinois Modified AASHTO T 259. The modifications to AASHTO T 259 are based on information provided by Wiss, Janney, Elstner and Associates and testing performed at the University of Minnesota [*4*]. Originally, the three percent solution specified by AASHTO T 259 was intended to simulate sea water. Salt concentrations of solutions typically found on bridge decks, however, are much higher than three percent. In a recent study, researchers at the University of Minnesota used a 15 percent salt solution to simulate solutions found on bridge decks. Also, in order to accelerate the test and simulate field conditions, a wetting and drying cycle was used: four days of ponding and three days of drying.

Samples were collected and tested in accordance with AASHTO T 260 after 23 and 31 cycles of ponding with 15 percent salt solution and drying, as described above. Background chloride ion contents were measured from samples that did not undergo ponding. These background contents represent the chloride content of concrete, found primarily in the aggregate particles. The background chloride ion contents were then subtracted from total chloride ion contents. Table 4 contains a summary of the test results.

Table 4.
Chloride Ion Contents At 23 And 31 Weeks
(Parts Per Million of Chloride Ions)

	23 weeks		31 weeks	
	Level A	Level B	Level A	Level B
Design 1	1652	0[a]	2296	176
Design 2	586	0[a]	1594	92
Design 3	2510	80	2617	603
Standard Design	1051[b]	132[b]	--	--

[a]Chloride ion contents were the same as or lower than background chloride ion contents
[b]Samples collected at 18 weeks
Level A at 1/2-in. depth; Level B at 1 1/2-in. depth

Testing of the standard microsilica design was limited to results at 18 cycles. At 23 weeks, Designs 1 and 2 had negligible chloride ion contents at Level B, while the present design averaged 132 parts per million at the same level. Even with 5 more cycles, Design 1 had lower average chloride contents at Level B than the present design. As expected, Design 2 had the lowest chloride contents at Level B.

At Level A, the standard design did have lower chloride ion contents at 18 weeks than Designs 1 and 3 at 23 weeks. Level A contents, however, are not as critical as contents at Level B, since Level B is closer to the level of the reinforcing steel. Designs 1 and 3 most likely had high Level A contents because early in their life they had higher permeability. As the pozzolanic reaction progressed, they became less permeable and allowed fewer ions into Level B.

The samples representing the standard design had water-cement ratios of 0.41, 0.43, 0.43, and 0.45. These samples used aggregates collected from four IDOT districts. Aggregate sources had previously been used in those districts for microsilica deck overlays. The water-cement ratios were the lowest attainable when using typical field superplasticizer dosage rates.

The three new designs were tested after 31 weeks of ponding. As expected, Design 2 had the lowest chloride ion contents at Levels A and B. Design 3 had more chloride ions at Level B after 31 weeks than the other new designs.

Rapid Chloride Permeability (RCP) Testing

The RCP test was modified from a six-hour test to an initial amperage test. The six-hour test consisted of recording amperage at thirty second intervals over a six-hour period. The total charge passed, in Coulombs, was then calculated. The equation for a best fit line (from a series of previous IDOT tests) was used to convert initial amperages to Coulomb values for all of the tests. All of the RCP tests were performed at 28 days. The curing consisted of 14 days in a moist room followed by 14 days of drying in laboratory conditions. Results are found in Table 5.

The average Coulomb value for Design 1 is only slightly higher than the present design. Design 2 attained the lowest Coulomb value, as expected. Design 3, however, had a Coulomb value much higher than expected. Prior studies have found that concrete containing fly ash may yield Coulomb values that do not correlate well with salt ponding data [*5,6*]. Also, because of the slower pozzolanic reactivity of fly ash compared to microsilica, the permeability of Design 3 will decrease over time.

Two recent articles [*6,7*] discuss the effects of concrete pore solution conductivity on the RCP test. The articles state that the RCP test overstates the influence that some mineral admixtures such as microsilica have on permeability. Microsilica increases the resistance of the pore water solution, which results in a lower Coulomb value. However, this change in the resistance of the pore water solution is not related to permeability.

Table 5.
Rapid Chloride Permeability Test Results

	RCP (Coulombs)
Design 1	1093
Design 2	560
Design 3	4650
Standard Design	949

The conditions and length of the curing period will also influence the RCP test. As the pozzolanic reaction progresses, the permeability will drop. Recent research suggest that 56 or 90 days may be a more appropriate curing period. Accelerated curing techniques have been used to achieve results similar to those obtained after up to six months of moist curing [*8*].

Initial Distress Surveys

All of the decks were surveyed for distresses between September and December of 1998. A summary of the results can be found in Table 6, and more detailed information is contained in Table C-1. The six overlays designated as "East" in Table 6 used concrete from the plant located in Springfield, and the 15 overlays designated as "West" used concrete from the Jacksonville plant. None of the Stage II overlays had more than two transverse, longitudinal, or random cracks, or more than 3-ft^2 of plastic shrinkage cracking. Seven of the 21 lanes in Stage I had only minor cracking.

Design 2 was used in two lanes on two adjacent structures during Stage I. One pour was completed in the morning of June 1, 1998, and the other in the afternoon of the same day. During the morning pour, the mix had a very low water-cement ratio (0.35 - 0.36). The longitudinal cracks found on the lane poured that morning (SN 069-0057) were most likely due to plastic shrinkage, and one 10-ft^2 area of randomly oriented cracks was very likely plastic shrinkage cracking. The very low water-cement ratio made the mix much more sensitive to plastic shrinkage. The mix water-cement ratio was increased to 0.37 - 0.38 in the afternoon (SN 069-0058), and no distresses were found in that lane.

Seven lanes had more than two transverse cracks. No distresses were found in 26 out of 42 lanes (62 percent), and none of the distresses found were moderate or severe. All of the seven lanes that had more than two transverse cracks and/or more than 3-ft^2 of plastic shrinkage cracking were in Stage I.

Table 6.
Summary of Distress Survey

	Stage I		Stage II		Total
	East (6)	West (15)	East (6)	West (15)	(42)
No Cracks	1	10	3	13	27
Negligible[a]	3	0	3	2	8
Minor[b]	2	5	0	0	7
% Minor	33%	33%	0%	0%	17%

[a] *two or fewer* cracks (other than plastic shrinkage cracks) and *less than 3-ft²* of plastic shrinkage cracking
[b] *more than 2* cracks (other than plastic shrinkage cracks) and/or *more than 3-ft²* of plastic shrinkage cracking; all cracks tight and no spalling

The driving lane of Structure 069-0043 contained about 60-ft. of transverse cracks, 43-ft. of which were found in the shoulder area. The bridge slopes downward towards the shoulder. The bridge also slopes downward towards the east abutment, where the placement started. Free water that was present on the deck at the time of the pour flowed towards the shoulder area, thus increasing the water-cement ratio in that area. This substantial localized increase in water-cement ratio is the most likely cause of the cracking.

Pull-off Testing (Illinois Modified ACI 503R) of Uncored Prepared Surface

Critical to the performance of the overlay is the condition of the surface to which it is bonded. Milling operations leave behind a thin, microfractured layer at the top of the original deck. If this weak, microfractured layer is not removed, then overlay performance is at risk [9]. In order to assess the strength of the top 1/8th inch of the milled surface, a modified pull-off test was used. Pull-off testing was performed on both the milled surface and the overlay itself. Pipe caps were attached directly to the milled surface using a two-component epoxy. Three caps were pulled before power washing and three were pulled after power washing. Power washing equipment operated at approximately 3000 psi. Tensile strengths are found in Table 7. These results indicate that the surface preparation methods were not adequate and did not provide a strong, intact surface. According to one source, the tensile strength of the bond between the overlay and the existing surface should be at least 250 psi [*10*].

Table 7.
Pull-off Testing of Uncored Surface

	Before Power Washing	**After Power Washing**
Tensile Strengths (psi)	95 102 111	115 121 127
Average Tensile Strength (psi)	103	121

NOTE: All specimens failed immediately below the surface.

Pull-off Testing (ACI 503R) of Overlay

As a follow-up to the testing of the milled surface, conventional pull-off testing was performed on four of the bridge decks. Three of the overlays tested used Design 1 and one used Design 3. Table 8 contains tensile strength data.

Of the 12 locations cored, eight were tested for pull-off strength and four broke prior to testing. Five of the eight cores that were tested failed completely or partially within the microfractured layer in the existing deck. The other three cores failed at the interface between the epoxy and the top of the core. These failures were most likely due to moisture interfering with the epoxy-concrete bond. The overlays were between three and four weeks old at the time of the pull-off tests.

Table 8.
Pull-off Testing of Overlay Bond

Structure Number	Core Number	Load at Failure (lbs)	Tensile Strength (psi)	Mode of Failure
069-0039	1	220	70	1
(fly ash)	2	190	61	1
	3	420	134	2
069-0041	4	170	54	1
	5	--	--	3
	6	--	--	3
069-0043	7	--	--	3
	8	400	127	2
	9	470	150	2
069-0049	10	520	166	1
	11	--	--	3
	12	400	127	1

Modes of Failure:

1. bond between overlay and original deck, Avg. Tensile Strength = 96 psi
2. bond between epoxy and core surface, Avg. Tensile Strength = 137 psi
3. broke prior to testing at bond between overlay and original deck

SUMMARY AND DISCUSSION

One of the most important characteristics of bridge deck overlay concrete is its permeability. If chloride ion intrusion is minimized, then the onset of corrosion will be delayed; or, if corrosion has begun, then the rate of corrosion will decrease. While the standard microsilica concrete overlay mix design has very low permeability, a number of problems are associated with it. Changes reflected in Designs 1 and 2 addresses these problems. Also, Design 3 was placed in order to evaluate a slightly higher permeability option for the special case of limited expected life extension or limited salt application.

In Designs 1 and 2, the amount of microsilica was lowered from 50 to 33 lbs/yd^3. This adjustment lowered water demand and allowed for a lower water-cement ratio to be used. Also, the amounts of coarse and fine aggregates were adjusted in order to reduce water demand further. This increase in the amount of coarse aggregate and decrease in the amount of fine aggregate reduced the total surface area of the aggregate blend, and thus lowered the overall water demand. The replacement of cement with fly ash in Design 3 reduced water demand and enhanced workability, allowing for the elimination of water reducer at the plant.

Twenty-one deck overlays were constructed in this study. Each overlay was constructed in two stages. Thirty-nine of the 42 pours utilized Design 1, two lanes were placed with Design 2, and Design 3 was used on one lane. According to both chloride ion content and RCP testing, Design 2 had the lowest permeability of the three new designs as well as the standard design. Design 1 performed similarly to the standard design in permeability testing. Not surprisingly, Design 3 had the highest permeability test results of all the designs.

Construction of the overlays took place between May 14 and August 17, 1998. Initial distress surveys were performed between three and six months after construction. Only seven of the 42 lanes had minor cracking at that time. Cracking in three of these lanes can be attributed to materials problems, two of which were due to the aforementioned confusion regarding the retarding admixture. Cracking in the third lane was most likely due to the use of an extremely low water-cement ratio. Of the remaining four lanes, minor cracking in three lanes can be attributed to construction problems. The cracking found in one of the seven lanes has no clear explanation.

Two of the lanes with construction-related cracking contained plastic shrinkage cracking. On the first pour, curing compound was not applied for more than one hour after finishing was completed, and shrinkage cracks appeared within hours of the end of the pour. Another lane with minor plastic shrinkage cracking was placed during severe environmental conditions (very high evaporation rates). Cracking may have been prevented by the addition of fogging behind finishing operations and quicker application of wet burlap.

The third lane with construction-related cracking contained five transverse cracks totaling about 50-ft. The cracks started at the parapet wall and stopped near the outside wheel path. These localized cracks were most likely caused by excessive water ponding in front of the paving operations. Water that was sprayed from the ready-mix trucks onto the deck immediately in front of the paving machine flowed towards the parapet wall. This excess water combined with the fresh concrete, effectively increasing the water-cement ratio. As water-cement ratio increases, so does shrinkage due to drying. This explains why the cracks occurred near the parapet wall and did not extend over the entire width of the pour, as is typical of drying shrinkage cracks.

Pull-off testing of both the milled surface and the bond between the existing deck and the overlay indicated that surface preparation methods were not adequate. Power washing equipment was either not being operated at high enough pressure, or the nozzle was held too far from the surface or not operated slowly enough. Pull-off testing of the bond between the overlay and existing deck further reinforced this finding. Pull-off strengths were low and failures primarily occurred in the existing deck just below the bond, in the microfractured zone.

Cost

The three contracts together consisted of 19,806 yd^2 of overlays. The bid cost of the microsilica overlays totaled $839,641. One contract also included a bituminous membrane overlay system for a county highway bridge over I-72. The average bid unit cost for the concrete overlays was $42.39/$yd^2$. These bid prices did not include deck patching or saw cut grooving. The combined bid prices of the three contracts totaled $2,769,684. Mix design changes will most likely not affect bid prices greatly. The three alternative mix designs will be less expensive due to smaller amounts of microsilica and superplasticizer in Designs 1 and 2, and replacement of cement with fly ash in Designs 2 and 3. The greatest potential cost savings may be due to the fact that contractors will find the new designs easier to construct. Placement operations should proceed more rapidly, and less time will be required for finishing.

CONCLUSIONS AND RECOMMENDATIONS

Designs 1 and 2 succeed in alleviating many of the problems associated with microsilica concrete deck overlays. Slump life is extended and overall constructability is improved. Furthermore, Design 1 provides comparable impermeability and strength, and Design 2 surpasses the performance of the standard microsilica design. The effects of replacing the standard design with Design 1 are summarized below:

- improved workability
- easier to finish, not as "sticky"
- significantly less superplasticizer required; therefore, slump loss is less severe
- similar permeability, according to RCP testing and Salt Ponding / Chloride Ion Content testing
- minimal loss in strength

Design 2 has the lowest permeability and the highest compressive and flexural strengths when compared to Designs 1 and 3, as well as the standard design. Design 3 has improved workability compared to the standard design, but strengths are lower and permeability is higher. The evaluation of the 42 overlays placed in 1998 will continue throughout their lifetimes. Designs 1 and 2 are currently allowed under the most recent revision of the special provision, and the standard design has been eliminated. Design 3, which contains fly ash and no microsilica, should be considered for bridges with a life expectancy of less than 15 years or minimal salt application.

Low permeability and low water-cement ratio mix designs do not guarantee successful overlays. The condition of the surface of the existing deck is critical to the performance of an overlay. In the case of milled surfaces, it is important to ensure that the microfractured layer remaining after milling operations be removed. The surface should be able to withstand over 250 psi of tensile force as determined by the surface pull-off test discussed earlier.

Applying water to the deck surface immediately ahead of placement has the potential to damage the bond as well as increase the water-cement ratio of the concrete. On at least one pour on I-72, this practice was the likely cause of transverse drying shrinkage cracking.

Curing is a critical part of the bridge deck overlay construction process. This field evaluation showed that by taking adequate measures, plastic shrinkage cracking can be prevented or minimized under even the most severe conditions. During the most severe conditions, the only other measure that could have prevented cracking would be covering the overlay with wet burlap sooner or applying additional fogging after curing compound was applied. A potential alternative to wet burlap, which is difficult to place when the surface is still subject to marring, is cotton matting. Cotton mats are lightweight and easier to place than wet burlap. Cotton mats would, however, need to be saturated immediately to prevent them from absorbing water from the overlay.

The following recommendations are made regarding construction of concrete deck overlays:

1. Require that the deck surface be kept in a saturated condition during the last 12+ hours before the pour. Do not allow water to be applied to the deck surface within 1 hour before, or any time during, placement.

2. Evaluate the use of water blasting as a surface preparation method when milling is used for concrete removal. Determine criteria for use of water blasting equipment or eliminate water blasting equipment.
3. Require wet burlap be applied as soon as possible after placement. In order to avoid marking deck with footprints, place burlap with work bridge. Consider allowing cotton mats.

The Resident Engineer for Contract 92930 hypothesized that stage construction can cause accelerated deterioration of older structures. All six of the bridges in Contract 92930 had higher percentages of patching on Stage II compared to Stage I. The Resident Engineer maintained that this deterioration was caused by doubling the traffic during the construction of Stage I. On structures 084-0127 and 084-0128, Stage II lanes were in such poor condition (more than 75 percent of the lane areas required patching) that no patches were placed. Instead, the deck was milled to the top level of reinforcement and an additional 1-1/2 to 2 inches was added to the overlay thickness. Stage I lanes had only 3.5 and 5.6 percent of the total lane areas patched. Fourteen of the 21 decks had higher percentages of patching on Stage II.

REFERENCES

1. ACI 305R-96, "Hot Weather Concreting," Manual of Concrete Practice, Part 2, American Concrete Institute, 1996.

2. Paul J. Uno, "Plastic Shrinkage Cracking and Evaporation Formulas," *ACI Materials Journal*, V. 95, No. 4, July-August 1998, pp. 365-375.

3. D. Whiting and R. Detwiler, *Silica Fume Concrete for Bridge Decks*, NCHRP Report 410, Transportation Research Board, 1998.

4. Tom Lorentz and Catherine French, "Corrosion of Reinforcing Steel in Concrete: Effects of Materials, Mix Composition, and Cracking," *ACI Materials Journal*, V. 92, No. 2, March-April 1995, pp.181-190.

5. John M. Scanlon and Matthew R. Sherman, "Fly Ash Concrete: An Evaluation of Chloride Penetration Testing Methods," *Concrete International*, V. 18, No. 6, June 1996. pp. 57-62.

6. Caijun Shi, Julie A. Stegemann, and Robert J. Caldwell, "Effect of Supplementary Materials on the Specific Conductivity of Pore Solution and its Implications on the Rapid Chloride Permeability Test (AASHTO T277 and ASTM C1202) Results," *ACI Materials Journal*, V. 95, No. 4, July-August 1998, pp.389-394.

7. Tie-Jun Zhao, Jin-Quan Zhu, and Pei-Yun Chi, "Modification of Pore Chemicals in Evaluation of High-Performance Concrete Permeability," *ACI Materials Journal*, V. 96, No. 1, January-February 1999, pp.84-89.

8. Celik Ozyildirim, *Permeability Specifications for High-Performance Concrete Decks*, Transportation Research Record No. 1610, TRB, 1998, pp.1-5.

9. Johan Silfwerbrand and Jonatan Paulsson, "Better Bonding of Bridge Deck Overlays," *Concrete International*, V. 20, No. 10, October 1998, pp. 56-61.

10. Michael M. Sprinkel, "Preparing Bridge Decks for Overlays," *Concrete Repair Digest*, October/November 1997, pp. 242-247.

Appendix A

Material Data

Table A-1.
Coarse Aggregate Gradations (Percent Passing)

sieve size	**CA11**	**CA14**	**CA16**
1-in.	100		
3/4-in.	84-100		
5/8-in.		100	
1/2-in.	30-60	80-100	100
3/8-in.		25-65	94-100
No. 4	0-12	0-6	15-45
No. 16			0-4
No. 200[a]	<2.5	<2.5	<2.5

[a]percent passing No. 200 sieve limited to 1.0% except for crushed aggregate when material consists of dust from fracture and is essentially free from clay or silt (2.5%)
NOTE: Taken from IDOT Standard Specifications for Road and Bridge Construction, January 1, 1997.

Table A-2.
Average Gradations for Aggregates Used in Field Mixes (Percent Passing)

sieve size	**Central Stone CA11**	**Central Stone CA14**	*sieve size*	**Buckhart S&G FA01**	**Otter Creek FA01**
1-in.	100	--	*3/8-in.*	100	100
3/4-in.	93	--	*No. 4*	98	96
5/8-in.	--	100	*No. 8*	90	90
1/2-in.	41	84	*No. 16*	75	81
3/8-in.	20	42	*No. 30*	55	61
No. 4	4	8	*No. 50*	17	13
No. 16	2.1	2.1	*No. 100*	2.1	1.4
No. 200	1.6	1.5	*No. 200*	0.9	0.5

Table A-3.
Cement Test Results

	River Cement	Continental Cement
fineness (m^2/kg)	368.6	367.1
7-day strength (psi)	4162	4858
28-day strength (psi)	5960	6163
Loss on Ignition	0.5	1.3
SO_3	2.7	2.9
MgO	2.8	3.2
SiO_2	20.6	20.7
Fe_2O_3	3.7	1.6
Al_2O_3	4.6	5.6
CaO	63.8	64.0
Na_2O	0.12	0.13
K_2O	0.64	0.16

Table A-4.
Fly Ash Test Results

	Mineral Solutions (Will County) Class C Fly Ash
Specific Gravity	2.74
S.A.I. (7-day)[a]	97.5
S.A.I. (28-day)[a]	98.4
Water Requirement	92.7
Sum (Si+Al+Fe)	59.4
SO_3	2.4
CaO	24.8

[a]Strength Activity Index (ASTM C 311)

Table A-5.
Microsilica Test Results

Specific Gravity	2.30
S.A.I. (7-day)[a]	109.5
S.A.I. (28-day)[a]	129.0
Water Requirement	111.6
SiO_2	90.51
SO_3	0.28
Moisture Content	0.41

[a]Strength Activity Index (ASTM C 311)

Appendix B

Construction Data

Table B-1.
Structure Locations and Pour Dates

Structure Number	Structure Location	Stage I Pour Date	Stage II Pour Date
069-0034[a]	NB/SB US 67 over I-72	6/12	7/24
069-0035[a]	EB over GW RR	6/3	7/21
069-0036[a]	WB over GW RR	6/3	7/21
069-0038[b]	EB at South Fork[d]	6/9	7/27
069-0039[b]	WB at South Fork[d]	6/9	8/17
069-0040[b]	EB over IL 4	6/10	8/4
069-0041[b]	WB over IL 4	6/24	8/17
069-0042[b]	EB at MauVaise Terre Creek	6/16	8/7
069-0043[b]	WB at MauVaise Terre Creek	6/23	8/11
069-0048[b]	EB at North Fork[d]	6/17	8/7
069-0049[b]	WB at North Fork[d]	6/17	8/10
069-0055[a]	WB at US 67 Bypass	5/28	7/16
069-0056[a]	EB at US 67 Bypass	5/27	7/16
069-0057[a]	WB over Massey Lane	6/1	7/20
069-0058[a]	EB over Massey Lane	6/1	7/20
069-0059[c]	over Spring Creek	5/22	7/31
069-0060[c]	over Spring Creek	5/26	7/31
084-0127[c]	EB over NW RR	5/14	7/7
084-0128[c]	WB over NW RR	5/14	7/8
084-0148[c]	over Wabash Ave	5/18	7/23
084-0149[c]	over Wabash Ave	5/18	7/23

[a] - Contract 72064
[b] - Contract 92929
[c] - Contract 92930
[d] - North and South Forks of MauVaise Terre Creek
NOTE: All bridges on I-72 except SN 069-0034 (US 67); all dates in 1998

Table B-2.
Historical Information on Structures

Structure Number	Deck/ WS[a]	Soffit Condition	Previous Overlays, Patching	Date of Construction
069-0034	6/3	good; spalling at deck joints since 1988	[b] / 1988 - bituminous overlay	1975
069-0035	7/3	minor transverse cracks since 1994	b	1975
069-0036	7/3	minor transverse cracks since 1994	b	1975
069-0038	8/3	good condition	b	1975
069-0039	8/2	good; delaminations at joint since 1996	b	1975
069-0040	7/3	light trans. cracks with a few delaminations.	b	1975
069-0041	7/3	light trans. cracks; spalling at joints	b	1975
069-0042	7/3	light trans. cracks; one spall near joint	b	1975
069-0043	7/3	trans. cracks w/ delam. since 1996	b	1975
069-0048	7/3	good condition	b	1975
069-0049	8/3	minor trans. cracks since 1996	b	1975
069-0055	7/3	minor trans. cracks since 1996	b	1978
069-0056	7/3	trans. cracks w/ delam. since 1994	b	1978
069-0057	7/3	good condition	b	1978
069-0058	7/3	good condition	b	1977
069-0059	7/2	light transverse cracks since 1996	b	1975
069-0060	7/3	light transverse cracks since 1996	b	1975
084-0127	6/3	delaminations at long. constr. jt. since 1994	1986 - partial depth patch (45%)	1969
084-0128	5/3	delaminations at long. constr. jt. since 1994	1986 - partial depth patch (30-40%)	1969
084-0148	6/3	trans. cracks w/ delam. since 1994	b	1973
084-0149	7/3	good condition	b	1973

[a]ratings based on scale from 0-9 for overall deck condition, 1-5 for wearing surface (WS) condition
[b]bituminous membrane system placed at time of original construction; oil and chip and/or cold patch repairs made since then

Table B-3.
Patching Quantities

Structure Number	Lane	Full Depth (yd²)	Partial Depth (yd²)	% of Deck Area Patched
069-0034	SB	0	2.9	0.5
	NB	0	1.6	0.3
069-0035	D	0	15.6	5.7
	P	0	19.0	5.6
069-0036	D	0	9.0	3.3
	P	0	4.5	1.4
069-0038	D	0	0.0	0.0
	P	0	0.0	0.0
069-0039	D	0	4.2	1.1
	P	0	10.7	3.5
069-0040	D	0	13.6	2.2
	P	0	6.9	1.4
069-0041	D	0	5.2	0.8
	P	0	18.6	3.7
069-0042	D	0	4.1	0.7
	P	0	7.8	1.7
069-0043	D	0	8.4	1.5
	P	0	19.3	4.2
069-0048	D	0	15.9	3.4
	P	0	38.8	10.1
069-0049	D	0	5.1	1.1
	P	0	1.3	0.4
069-0055	D	0	5.6	0.5
	P	7.0	13.6	3.8
069-0056	D	7.1	10.9	1.7
	P	0	0.2	0.1
069-0057	D	0	1.6	0.7
	P	0	2.8	1.4
069-0058	D	0	0.0	0.0
	P	0	0.6	0.3
069-0059	D	0	0.0	0.0
	P	0	0.3	0.1
069-0060	D	0	0.0	0.0
	P	0	2.7	1.1
084-0127	D	0	40.6	5.6
	P	0	[a]	>75
084-0128	D	0	25.1	3.5
	P	0	[a]	>75
084-0148	D	0	2.2	0.4
	P	0	12.6	2.9
084-0149	D	0	6.0	1.1
	P	0	7.3	1.7

[a]over 75% of lanes needed patches

NOTE: D=driving, P=passing, SB=southbound, NB=northbound, where D and SB lanes are Stage I, and P and NB lanes are Stage II.

Table B-4.
Evaporation Data

Date/Time	Relative Humidity (%)	Wind Speed (mph)	Air Temp. (°F)	Concrete Temp. (°F)	Evap. Rate (lb/ft²/hr)
5/14/98	*SN 084-0128 until 12:00; SN 084-0127 after 1:30, both Stage I*				
7:35	62	5.7	73	76	0.07
8:30	62	10.2	77	78	0.10
9:00	63	10.2	79	80	0.11
9:45	60	10.2	81	82	0.12
10:50	43	14.2	87	85	0.23
14:50	35	18.8	91	89	0.38
16:00	41	19.3	90	89	0.36
5/18/98	*SN 084-0148 Stage I*				
10:55	30	18.2	86	89	0.43
5/27/98	*SN 069-0056 Stage I*				
9:50	65	6.8	70	72	0.06
10:05	75	4.5	73	75	0.04
11:40	50	4.5	82	84	0.09
12:20	57	10.2	82	85	0.16
5/28/98	*SN 069-0055 Stage I*				
10:05	65	13.1	79	85	0.18
10:40	60	13.1	80	87	0.22
12:00	56	13.6	84	90	0.26
6/1/98	*SN 069-0058 Stage I*				
13:00	32	4.5	75	80	0.11
13:30	37	10.2	76	80	0.19
6/12/98	*SN 069-0034 Stage I*				
11:00	60	16.5	82	85	0.22
11:45	65	13.1	85	85	0.14
12:30	65	12.5	85	85	0.13
7/16/98	*SN 069-0055 Stage II*				
6:30	85	4.5	69	84	0.08
7:20	77	9.1	72	85	0.15
8:40	58	12.5	81	85	0.19
9:55	50	12.5	83	86	0.22
10:50	57	14.8	83	86	0.22
8/11/98	*SN 069-0043 Stage II*				
7:15	83	4.5	69	86	0.10
8:20	76	8.0	74	86	0.13
8/17/98	*SN 069-0041 Stage II*				
7:25	83	6.8	71	81	0.08
8:40	70	6.8	77	82	0.09
9:30	60	14.8	81	82	0.17

Appendix C

Distress Survey Results

Table C-1.
Initial Distress Survey Results

Structure No.	**Comments**
069-0034	SB - 2 transverse cracks, both 1/2 lane-width, one by north abutment, other in northern 1/3rd of deck NB - no cracks
069-0035	DL, PL - no cracks
069-0036	DL, PL - no cracks
069-0038	DL, PL - no cracks
069-0039	DL - no cracks; PL - no cracks (Des. 3)
069-0040	DL, PL - no cracks
069-0041	DL, PL - no cracks
069-0042	DL - 1 transverse crack in traffic lane ~12-ft. long PL - 1 transverse crack ~10-ft. long
069-0043	DL - 5 transverse cracks totaling ~60-ft. PL - no cracks
069-0048	DL - 3 longitudinal cracks, two of which emanate from west expansion joint; two randomly oriented cracks PL - no cracks
069-0049	DL - no cracks PL - 1 longitudinal crack at east end ~16-ft. long
069-0055	DL - 3 transverse cracks totaling 45-ft.; ~30-ft. long. cracking at 30-ft. for east abutment; 1-ft^2 of plastic shrinkage cracking PL - 1 transverse crack across full width
069-0056	DL - ~15-ft. of long. cracking at three locations, near east and west abutments, and halfway point; 10-ft^2 area of plastic shrinkage cracking PL - no cracks
069-0057	DL - ~50-ft. of longitudinal cracking in right and left wheel paths at east end, some transverse cracking (Des. 2 - a.m.) PL - no cracks
069-0058	DL - no cracks (Des. 2 - p.m.); PL - no cracks
069-0059	DL, PL - no cracks
069-0060	DL, PL - no cracks
084-0127	DL - no cracks PL - one transverse crack (half lane-width); marks from rain drops, surface scaling (low severity)
084-0128	DL - plastic shrinkage cracking in middle third (cracks sealed in several areas); transverse crack in shoulder PL - no cracks; marks from rain drops, slight surface scaling
084-0148	DL - tight plastic shrinkage cracks in western-most 1/3rd; crack perpendicular to east expansion joint PL - crack perp. to east expansion joint; small Y-crack at east end
084-0149	DL - total of ~3-ft^2 of plastic shrinkage cracking PL - no cracks